Bioelectromagnetics

Letter

Setting Guidelines for Electromagnetic Exposures and Research Needs

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Current limits for exposures to nonionizing electromagnetic fields (EMF) are set, based on relatively short-term exposures. Long-term exposures to weak EMF are not addressed in the current guidelines. Nevertheless, a large and growing amount of evidence indicates that long-term exposure to weak fields can affect biological systems and might have effects on human health. If they do, the public health issues could be important because of the very large fraction of the population worldwide that is exposed. We also discuss research that needs to be done to clarify questions about the effects of weak fields. In addition to the current short-term exposure guidelines, we propose an approach to how weak field exposure guidelines for long-term exposures might be set, in which the responsibility for limiting exposure is divided between the manufacturer, system operator, and individual being exposed. Bioelectromagnetics. © 2020 Bioelectromagnetics Society

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INTRODUCTION

The Institute of Electrical and Electronics Engineers (IEEE) and International Commission on Non-Ionizing Radiation Protection (ICNIRP) have both recently issued the revised guidelines for exposures to electromagnetic fields (EMF) from 0 (DC) to 300 GHz [IEEE, 2019; ICNIRP, 2020]. They somewhat modify the existing guidelines on exposures [IEEE, 2005; ICNIRP, 2009a for static magnetic fields; ICNIRP, 2010 for low-frequency fields; ICNIRP, 2009b for high-frequency fields] in forming the basis of standards in most countries around the world. Though recently revised to some extent, the recommended limits on exposure have not changed very much since 1998. Current exposure limits are based at low frequencies on externally applied electric fields being large enough to stimulate the firing of a nerve cell at approximately 5,000 V/m and at higher frequencies on specific absorption rates, SAR in W/kg, large enough to cause temperature rise of approximately 1 °C over a period of 6 min. In the 30–300 MHz range, this typically corresponds to incident powers of about 10 W/m^2. Both IEEE and ICNIRP base their analyses on rigorous reviews of the scientific literature and on established firm evidence of health effects in humans. The present guidelines are based on acute exposures; to date both IEEE and ICNIRP have not found sufficient evidence to include health effects of long-term exposures at lower levels.

However, over the last 20 years the evidence has become extremely strong that weaker EMF over the whole range for frequencies from static through millimeter waves can modify biological processes. There is now solid experimental evidence and supporting theory showing that weak fields, especially but not exclusively at low frequencies, can modify reactive free radical concentrations and that changes in radical concentration

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and that of other signaling molecules, such as hydrogen peroxide and calcium, can modify biological processes [Batchelor et al., 1993; Bingham, 1996; Timmel et al., 1998; Woodward et al., 2001; De Iuliis et al., 2009; Castello et al., 2014; Li and Heroux, 2014; Usselman et al., 2014; Barnes and Greenebaum, 2015]. Static and low-frequency magnetic fields have shown both acceleration and inhibition of cancer cell growth rates in the culture [Bingham, 1996; De Iuliis et al., 2009; Castello et al., 2014; Li and Heroux, 2014; Gurhan et al., 2020]. Both the acceleration and inhibition of growth rates of planarian [Van Huizen et al., 2019] have been demonstrated with static magnetic fields in the range from 0.5 to 600 μT. At radio frequencies, both increases and decreases in cancer cell growth rates have been measured in the range from 1.8 to 7 MHz for power densities of less than 0.1 W/m^2 and a magnetic flux density of 24 nT [Castello et al., 2014; Usselman et al., 2014; Vijayalaxmi et al., 2014; Usselman et al., 2016]. Other examples include changes in male fertility [Avendano et al., 2012]. See also book chapters by Feychting et al. [2017] Kheifets et al. [2017] and Wood and Loughran [2017] for reviews of studies that show positive, negative, and no changes for exposures to weak EMF. We argue below that experimental results showing positive, negative, and no changes in the same parameter are not invariably the evidence of poor experimental controls but also arise because of inherent feedback processes where the biological system adjusts to bring the system back to the desired operating conditions [Barnes and Kandala, 2018]. Additionally, it is very difficult to control and repeat the initial slightly different conditions in the organism; and small differences can lead to different results.

The evidence that weak radiofrequency (RF) and low-frequency fields can modify human health is still less strong, but the experiments supporting both conclusions are too numerous to be uniformly written off as a group due to poor technique, poor dosimetry, or lack of blinding in some cases, or other good laboratory practices. Based on recent studies by the National Toxicology Program (NTP) [Smith-Roe et al., 2020] and the Ramazini Foundation [Falcioni et al., 2018] as well as laboratory data, the International Agency for Research on Cancer (IARC) has declared RF fields as possible human carcinogens [IARC, 2013]. A recent paper extends the NTP studies by evaluating genotoxicity in animals exposed to fields at or over the guideline limits and found DNA damage in Comet assays [Smith-Roe et al., 2020]. Many other papers indicate similar results, but many negative results are also in the literature. The papers presenting the guidelines themselves and the literature reviews supporting them present some of these references, including WHO [1993, 2007a,b] and ICNIRP [2009a,b, 2010]. Others may be found in IARC [2013], Belyaev et al. [2016], Zhang et al. [2017], Sienkiewicz and Van Rongen [2019], Elwood and Wood [2019], and Stanley and Friedman [2019], as well as in many others. Lin [2018, 2019] has critically reviewed the strengths and weaknesses of the NTP studies. A recent advisory panel has recommended to IARC that RF radiation be a part of the list of agents whose carcinogenicity is reassessed in the next 5-year period [IARC, 2019].

The results of these papers have not been considered convincing or relevant by the reviewing organization's panels due to methodological issues, because they did not relate closely enough to human health, and because the experimental results are mixed, showing increases, decreases, or no change in similar situations. However, taken as a group they do provide strong evidence that weak EMF can be sensed by biological systems, as well as suggestive evidence that fields may affect human health.

At least part of the explanation for the mixed results is likely to be that biological feedback processes often cancel out perturbations that would otherwise take biological systems out of their normal operating range [Vijayalaxmi et al., 2014]. For example, if we exercise, the body temperature starts to rise, and we begin to sweat in order to limit the temperature rise to within the normal operating range. If we get cold, we start to shiver. With EMF we appear to be modifying oxidative stress [De Iuliis et al., 2009; Castello et al., 2014; Usselman et al., 2014, 2016], cancer cell growth rates [Castello et al., 2014; Usselman et al., 2014, 2016; Sherrard et al., 2018], membrane potentials [Ye and Kaszuba 2019], and concentrations of calcium, reactive oxygen species (ROS), superoxide ($O2^-$), nitric oxide (NO), hydrogen peroxide (H_2O_2), and intercellular pH [Cichon et al., 2017; Gurhan et al., 2020; Osera et al., 2015; Sonntag, 1998]. The body reacts to bring these levels back to within the normal operating range, but there is a time delay in these feedback processes. For periodic inputs, this can lead to either amplification or attenuation of the perturbation. There are many oscillating systems in the body, so the timing of the perturbation makes a difference, just as it does in how pushing a swing at the peak accelerates it, while pushing in the same direction at the bottom slows it down. Dröge [2002] reviews data on oxidative stress that show oxidative stress may be increased by a factor of ten or more for short times during exercise and returns to the normal range upon relaxation. He also shows that long-term elevations of the ROS lead to a shift in the baseline levels, and the elevated levels are associated with cancer, aging, and Alzheimer's. The effects of oxidative stress and other radicals are covered in detail by Halliwell and Gutteridge [2015].

As a result of limited data showing health effects from exposures that are acceptable within the current guidelines limiting exposure, controversies have arisen concerning whether the guidelines and the standards based on them are at an appropriate level, especially with regard to RF devices. Many existing or new uses of these technologies currently expose the user to more low levels of EMF than in the past. Due to improvements such as higher circuit sensitivity and the use of hands-free or speakers on telephones or instant messaging instead of phone calls, exposure from a single phone call is reduced, but in general the overall usage has increased. The need for higher data rates has led to the use of higher frequencies and more base stations, closer together and a reduction in transmitter power. The spreading use of RF technology and the application of it to new uses and higher frequencies have fed suspicion that the health of the public is at risk from extended, low-level exposure. Fear is heightened since some diseases, including autoimmune diseases, are on the rise. In addition, some individuals who have symptoms or diseases, ranging from pains of unknown origin to specific diseases, are convinced that EMF exposure is the cause, sometimes called idiopathic intolerance attributed to EMF (IDI-EMF). However, a number of controlled laboratory experiments that expose them blindly to fields or no-fields has not produced any correlations between the symptoms and the subjects' ability to identify if the fields were on or off [Hansson Mild et al., 2006; Verrender et al., 2018].

At the same time, the greater usefulness and convenience of the same RF technologies has embedded them more deeply into all levels of both highly developed and developing societies. The portable, hand-held cell phone device is not going away, nor will the other uses of RF technology. Indeed, the range of frequency exposures will expand further with the advent of 5G technology. At present, the current standards are saying that there is no evidence that fields are harmful, and the attention of the regulators, funding agencies, and others is directed elsewhere. But there is also a growing collection of scientific results from laboratories in the United States, Europe, Japan, China, and elsewhere that says that EMF do have effects, as well as a small but vocal group of people inside and outside of science who are positively convinced that we are harming ourselves with the growing use of RF technology.

NEXT STEPS IN FURTHER RESEARCH

At the present time, we do not know what exposure conditions lead to resetting the baselines for the concentrations of reactive oxygen and other molecules that lead to problems such as oxidative stress and how these conditions are associated with cognitive effects, aging, cancer, and other diseases. We hypothesize that this is a potential cause for health effects, while other causes may also exist. While data exist on the current levels of exposure from 4G and earlier versions of mobile phones, and theoretical estimates exist on the levels of exposure that will exist with the higher frequencies of 5G systems that are currently being installed or contemplated, we currently have only very limited good data on 5G. One important research need is to measure these exposure levels under various actual conditions. It is currently not clear that, with focused beams and higher data rates leading to shorter-on times, whether the personal exposures will increase or decrease with the increased number of lower-power base stations.

Considerable research work needs to be done to solidify the effects identified above, as well as many others. This work must be done carefully, using the best laboratory practices and sufficiently large samples to produce significant results [e.g., Valberg, 1995; Portelli 2019]. It may be useful, especially if funding comes from a pool contributed by industry, to establish and fund a small oversight group of distinguished bioelectromagnetics scientists, to choose projects and monitor them onsite, ensuring that they are likely to accomplish their goals. This group would be similar to the ones used by the Navy, Environmental Protection Agency (EPA), National Institute of Environmental Health Sciences (NIEHS), the New York State Power Authority, and others in the 1970s and 1980s [Dietrich, 1998].

The research on oxidative stress and feedback loops discussed above should identify when changes in the concentrations of these and other molecules lead to concentrations that are not corrected by the body's feedback and control systems or through other mechanisms, and have increased the probabilities for causing adverse health effects. For example, experiments could be done in the cell phone and wireless bands at different power levels for different numbers of hours per day and days per week to see when the concentration levels of H_2O_2, NO, and other molecules leading to oxidative stress change to levels outside the normal range. This could be a variation on the National Toxicology Program study [Smith-Roe et al., 2020] and Ramazzini study [Falcioni et al., 2018]. This study would need to be coupled with biochemical studies on when changes in these molecular concentrations lead to problems. Measurements need to be made on the changes in biological parameters, such as reactive free radical concentration, Ca, NO, H_2O_2, and other signaling molecules, as a function of the exposure parameters. This needs to be at levels ranging from molecules in solution through cell culture and whole animals to humans. These results need to be used to develop models that can be correlated with epidemiological studies to minimize exposure conditions that lead to undesired health effects or at least to the ability to predict the probability of a health effect under varying patterns of use. These are likely to be functions of the user's age, health, and other stresses.

An example of projects that might be initiated would look at the possible effects of 5G signals on the growth of melanoma. The first experiment might be to look at the skin under exposure to 5 G signals to see if there are changes in the levels of reactive oxygen and other signaling molecules, such as hydrogen peroxide and calcium, as a function of exposure parameters such as intensity and length of exposure. A second set of measurements might be to look at changes in the growth rates of melanoma cells in the culture as a function of intensity and length of exposure. These experiments might have two objectives. The first would be to find the minimum signal that modifies growth rates, and the second might be to see if there are exposure parameters that inhibit or accelerate its growth. A third set of experiments could be to look at animal models. The third set of experiments is likely to be expensive, requiring an effort on the order of the NTP studies, and could include additional measurements on the changes in chemistry as function of time and exposure parameters. A fourth set of experiments, if there turns out to be exposure parameters that inhibit the growth of melanoma, might be on humans. Many other examples of following up effects that have significant backing in the literature could be proposed.

Funding for research into the effects of EMF in the United States is close to nonexistent, though the National Institutes of Health (NIH) and the Defense Department have a few mission-related programs. Elsewhere, support is better, though a great deal of European funding is concentrated on aggregating prior results or on the question of idiopathic intolerance or hypersensitivity. We believe a carefully targeted program of federal research funds is called for, supplemented by communications system operators and corporations that manufacture equipment, under independent scientific management. Both governmental and private entities that emit RF signals would be well advised to fund research to elucidate and define threshold signal levels for the generation of long-term biological effects. Given the way the current product liability law works, an able lawyer might well convince a jury that exposures within the current limits have caused cancer, cognitive disabilities in children, etc., which could cost billions of dollars.

PROPOSED APPROACH TO SETTING EXPOSURE LIMITS

From these and other lines of solid research, the guidelines for exposure could be revised. Increased emphasis on long-term exposures may require refining the concept of dose to more flexibly combine exposure time and field intensity or energy absorbed. Eventual guidelines might suggest limiting cell phone calls to X hours per day with exposure levels above Y W/m^2, and for Z days per week exposure should be less than Y W/m^2 to allow the body to reset its baseline. The time between heavy exposures might be initially estimated by looking at recovery times from other stresses such as exercise. Major league starting pitchers usually are given several days between starts. In other cases, overnight may be good enough. Training also increases the speed of recovery. A possibility might be that cell phones and WiFi are turned off at night or over the weekend to allow for resetting of the oxidative baseline levels.

Even as further research is needed, an approach to setting exposure limits should be considered. We would like to propose that a starting point might be to consider the way standards are set for driving a car. Virtually everyone knows that driving a car can be dangerous, but most of us still drive them. With automobiles we have rules of the road, such as which side of the highway we drive on, and speed limits that vary with location and with further adjustments for conditions such as rain and snow, set by competent authorities. Most of us consider that the value of traveling by car is greater than the risk. For cell phones and other devices, suggested limits might be recommended on the field strengths, length of exposure, and times in between use. These recommended limits could well be a function of frequency, amplitude, and modulation systems and will clearly depend on the condition of the person being exposed. Some people will be more sensitive than others and the sensitivity of a given individual could well change with time. It is likely over time that we will find that some frequency and patterns are more biologically active than others are. However, we have yet to achieve consensus on these questions, in part because the research on linking exposure to weak EMF directly to human health is too weak to make a convincing argument for foregoing the convenience of cell phones and other electromagnetic devices.

Currently, our standards seem to be effective in preventing easily demonstrated biological damage for short-term exposure for most people. However, it is not clear whether the biological effects seen for lower levels of exposure and long-term exposure are not resulting in medical problems for a much larger number of people. Additionally, there seem to be a smaller number of "hypersensitive people" who have very real and serious problems that they believe are based on exposure to weak RF fields. What is missing in the current guidelines or regulations are guidelines for long-term exposure to weak EMF.

Guidelines should be set at three levels: the individual user, local company, and national or international level. An important issue is, what part of limits on exposures should be placed on the manufacturers and system operators, if any, and what part should be left to the user to control. For example, the problem of limiting the number of hours of use may well be up to the user to decide, given the information that is known at the time. The individual user is already, consciously or unconsciously, setting personal limits, though without external guidance. The user does or does not use RF equipment of various types, does or does not set limits on how long and how frequently to use it, does or does not decide to use hands-free mobile phone accessories or speaker phones, etc. External guidance, in terms of informed recommendations or at least analysis of various intensities and styles of usage from some agency such as the Federal Communications Commission (FCC) or NIH, would be useful.

Limits on the time for operations of base stations and exposures in adjacent living spaces are not controlled by the user and must be set by competent authorities, based on scientific evidence. It is likely to be difficult to specify times when exposures to RF signals are zero or below some limit. What will be needed is being able to say with some certainty that exposure below a given level has not been shown to cause changes in body chemistry above some level. A starting point might be current levels from TV and radio stations that are large enough to give signal-to-noise ratios around 20 dB (100-fold) with typical receiving systems. Currently, mean values for the population's exposure to these systems are estimated to be around 0.1 V/m and peak exposures range up to 2 V/m, which exceed current exposure limits for a small fraction of the population. Therefore, one starting point for exposure limits might be an average of 0.1 V/m, not based on research but on practicality, until further research results dictate either a lower or higher limit.

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